FORCES EXERTED ON TIES OF COMPRESS UNIVERSAL DENSITY COTTON BALES

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FORCES EXERTED ON TIES OF COMPRESS UNIVERSAL DENSITY COTTON BALES

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ABSTRACT

For economy in shipping and handling, as well as improvement of acceptance of American cotton in foreign markets, the universal density bale has been developed and promoted in the United States. The introduction of the universal density bale has raised questions as to the selection of suitable materials to be used for tying bales. The forces developed on ties for the compress universal density bales were investigated to provide a basis for selecting bale tie materials. Figures for required tie strength and a prediction equation for the forces are presented.

INTRODUCTION

The introduction of the universal density bale as the preferred bale package has greatly improved the acceptability of U.S. cotton in both overseas and domestic markets. Reports from foreign markets indicate that interest in U.S. cotton has been revived by favorable experience with the universal density bale. The Cotton Committee of the American Textile Manufacturers Institute has reported that the new bale package is completely acceptable to major U.S. textile mills as a result of favorable experience with processing the universal density bale in 1973.[2]

The universal density bale is one that is pressed in a gin or re-pressed in a compress (without the use of side pressure) to a density of 28 lb/ft^3 or greater. The National Cotton Council suggests dimensions of 21 by 25 by 58 inches for compress universal density bales and 21 by 26 by 55 inches for gin universal density bales, so that the bales will be acceptable to both domestic and export market mills and will be eligible for the lowest possible freight rates.[3]

The universal density bale may be produced in the gin by a gin universal press capable of packing bales to the required density, or it may be packaged initially at the gin in a modified flat bale press and then further compacted by re-pressing in a compress to the higher density. The universal density bale, however pressed, has gone a very long way toward the goal of acceptability in all markets.

Concurrent with the development and adoption of the universal density bale, the cotton industry shifted to net-weight trading. This move resulted in an average bale weight increase of 10 to 20 pounds per bale. Several strapping products for packaging universal density bales have been proposed for test-packaging programs and, in some instances, for use on a commercial basis. All these changes have raised questions as to what is required to strap and hold compress universal density bales.

Tie breakage is expensive, because it may involve re-pressing the bale, which is especially difficult after the bale has left the gin or compress and entered trade channels. Energy shortages also demand that diligent effort be applied toward efficient use of energy. The energy consumed in bale packaging can be kept to a minimum by efficient design of bale-tying materials, bale packages, and press systems.

Research was conducted at the U.S. Cotton Ginning Laboratory to provide information that would enable the cotton industry and packaging

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[2]Universal density bale making friends abroad for U.S. cotton industry. Cotton Gin and Oil Mill Press 74(20): 14. 1973.

[3]Universal Bale Committee, National Cotton Council. 1972. A universal bale for universal benefits. National Cotton Council of America, Memphis, Tenn. (Pamphlet.)

material suppliers to select bale ties with adequate strength to hold compress universal bales without excessive breakage.

TEST DESIGN

A randomized complete-block statistical design with two replications was used to estimate the force that must be held by the bale ties. The force on the ties was correlated with moisture content (wet basis), platen separation to which the bale is pressed before it is released from the compress, and bale circumference at the tie after the bale is released from the compress and allowed to expand.

Sixteen modified flat bales of lint cotton were processed through a commercial compress and tied in eight places with size 50 roller chain. Eight of the bales were ginned at low moisture at the U.S. Cotton Ginning Laboratory; eight others were selected at random from storage at the commercial warehouse where the experiment was conducted. The experiment involved two lint moisture contents, two platen separations, and four bale circumferences. Eight bales were processed at 3.7 percent moisture and eight at 5.8 percent moisture.

Within each moisture level, four bales were re-pressed to a platen separation of 12.25 inches; two of these were held to a bale circumference at the tie of 76.12 inches, and two at a circumference of 83.62 inches. Four additional bales were re-pressed to a platen separation of 14.38 inches; two of these were held to a circumference of 80.00 inches, and two at a circumference of 87.38 inches. The net bale weights were maintained at approximately 500 pounds.

INSTRUMENTATION

The force exerted on each tie was measured with calibrated strain-gage transducers. Temperature and bending compensation were provided by the method of arranging the strain gages on the transducer and the method of connecting them into the Wheatstone bridge (fig. 1).

The strain-gage transducers were calibrated by connecting them in series with a factory-calibrated load cell. Force was applied, and the outputs of the transducers were plotted against the output of the calibrated load cell.

Seven of the eight strain gages were 8 by 3 by $\frac{3}{16}$ inches; the eighth one was 8 by 2 by $\frac{1}{4}$ inches. (The necessity for two sizes of transducers will be explained later.)

The transducer outputs were recorded on an eight-channel recorder for a minimum of 20 minutes for all bales; the forces on the ties of one bale were recorded continuously for 16 hours. The recorder was equipped with a time/event marker, permitting force to be monitored as a function of time. Roller chains (size 50) were used as bale ties instead of the conventional straps, bands, or wires because of the additional strength requirements for the experimental bales. Bale circumferences were measured on the inside of the roller chain link plates.

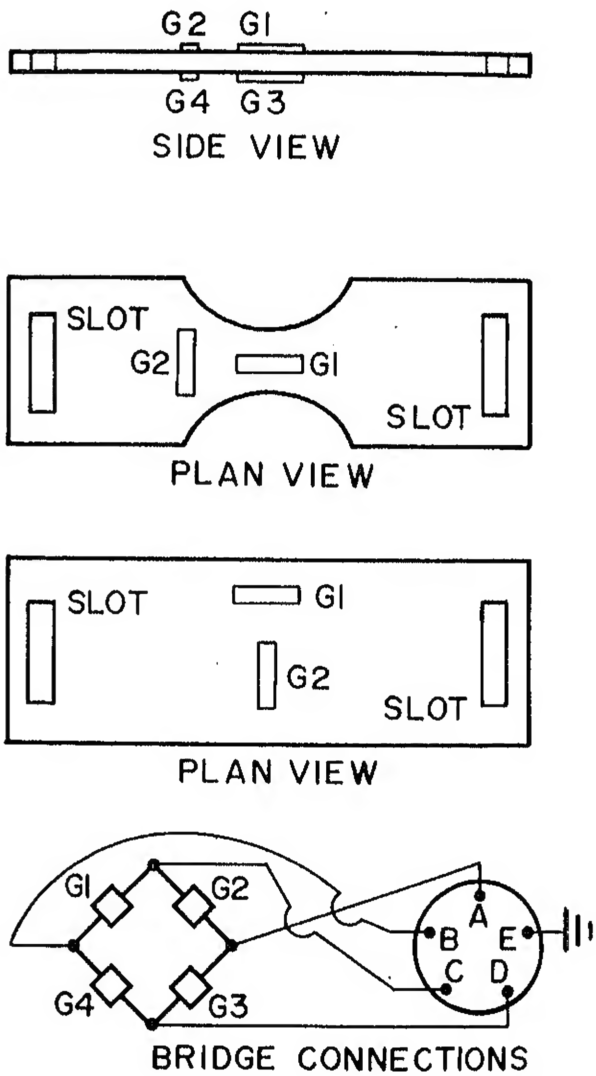

FIGURE 1.—Typical strain gage (G) placement (side and plan views) and Wheatstone bridge connections of the transducers.

RESULTS

A modified flat bale re-pressed to a platen separation of 12.25 inches in a compress is shown in figure 2. After the bales were pressed to the desired platen separation, the transducers and bale ties (No. 50 roller chain) were applied. On the first bale processed, only seven transducers were applied because of the uneven spacing on the two end ties (fig. 3), which prevented the placement of two 3-inch-wide transducers in adjacent ties. To avoid this difficulty on the 15 remaining bales, a smaller transducer (2 inches wide) was used in one tie. Uneven spacing of the bale ties is evident on most bales produced in a compress.

The variation in forces exerted on the ties of the test bales is shown in table 1. Not all the experimental bales were classified as compress universal density bales, since the bale circumference was intentionally varied. The density of the bales after they were released from the compress ranged from 25 to 33 lb/ft^3, and only those bales over 28 lb/ft^3 may be classified as universal density. The force exerted on the ties varied with tie location, depending upon the characteristics of the original ginning system where the bales were produced.

Previous work has also indicated that the force exerted on an individual bale tie varies with its location on the bale. This variation is not consistent among ginning systems but is consistent within a ginning system. However, the total force exerted on the bale ties, obtained by adding the forces on all individual ties, has been found to be consistent among ginning systems.[4] For this reason the total force exerted on the eight ties of the bale was used as the dependent variable. The effect of the independent variables on the total bale-tie force is shown in table 2.

[4]Anthony, Stanley, and McCaskill, Oliver L., 1973. Forces involved in packaging lint cotton. Cotton Gin and Oil Mill Press 74(15): 7–11.

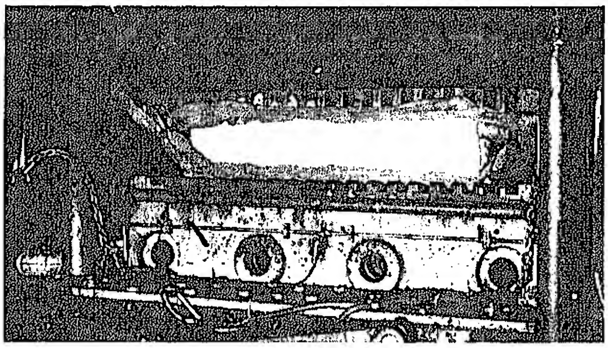

FIGURE 2.—Modified flat bale re-pressed to a platen separation of 12.25 inches in a commercial compress.

TABLE 1.—*Forces exerted on individual bale ties on modified flat bales re-pressed in a compress*[1]

Bale number	Moisture content[2] (percent)	Platen separation[3] (inches)	Bale circumference[4] (inches)	Bale-tie force (pounds) by tie position							
				1	2	3	4	5	6	7	8
1	3.80	14.38	87.38	750	845	865	790	715	805	585	735
2	3.88	14.38	87.38	830	860	850	860	755	780	790	670
3	4.02	14.50	80.18	2,240	2,620	3,050	3,600	3,400	3,540	3,200	2,960
4	3.62	14.38	80.18	3,200	3,320	3,600	3,760	2,900	2,480	2,100	2,300
5	3.59	12.25	83.62	430	300	400	440	420	445	270	386
6	3.94	12.25	83.62	645	470	435	460	450	400	390	464
7	3.56	12.38	76.12	2,060	2,280	2,160	2,000	2,080	2,040	2,070	1,360
8	3.43	12.38	76.12	2,400	2,000	2,100	1,420	2,200	1,880	1,620	1,240
9	5.47	14.38	87.38	680	710	670	560	600	700	650	390
10	5.03	14.38	87.38	720	650	750	600	780	710	1,170	800
11	7.02	14.38	80.00	1,800	2,320	1,660	1,490	1,910	2,200	1,680	1,800
12	5.42	14.38	80.00	1,700	2,360	2,160	2,170	2,040	2,590	2,160	1,220
13	5.59	12.12	83.62	555	575	680	340	455	450	465	500
14	5.71	12.38	83.62	375	305	440	340	500	450	320	520
15	6.11	12.25	76.12	1,880	2,220	2,360	1,930	2,300	2,340	1,900	2,200
16	6.10	12.25	76.12	1,810	2,350	2,400	2,035	2,440	2,620	2,040	2,200

[1]Based on modified flat bales 25 inches wide and 55 inches long, having 8 ties per bale. Forces were measured 20 minutes after release of platen pressure.

[2]Values are averages of 5 samples.

[3]Platen separation to which the lint cotton was re-pressed before the bale was released from the compress.

[4]Average for 8 ties per bale, measured at the ties after the bale was released from the compress.

To predict the total force exerted on the eight bale ties, a multiple linear regression analysis was performed on the data in table 2; the following equation resulted:

$$\log F = 25.9848 - 0.0170M - 15.4297 \log C + 6.7085 \log PS, \qquad (1)$$

where F=total force exerted on eight bale ties (pounds),

M=percentage of lint moisture (3.4 to 7.0 percent, wet basis),

C=bale circumference at the tie after the bale is released from the compress (76.12 to 87.38 inches),

and PS=platen separation to which cotton is pressed before the bale is released from the compress (12.25 to 14.38 inches).

Equation 1 is valid only for 500-pound bales (net) initially packaged in a modified flat press. The coefficient of determination (R^2) of equation 1 was 0.96, indicating that 96 percent of the variation in the force exerted on the bale tie was due to the independent variables. The analysis of variance for the regression is shown in table 3. The highly significant F-value indicates that the reduction in total sum of squares of the dependent variable as a result of the independent variables is not due to chance.

The relative importance and direction of influence of each of the three independent variables is shown in table 4. The computed t-values and standardized partial regression coefficients indicated that bale circumference and platen separation were highly significant (1 percent level of probability), and that moisture content was not significant (5-percent level of probability). Moisture content was included in equation 1 because it increased the coefficient of determination from 0.95 to 0.96. The standard error of the estimate was 0.0771, which indicates that a variation of 1.95 percent in the dependent variable (total bale-tie force) will be present near the center of the range.

The results of evaluating equation 1 within its valid levels are shown in table 5. The values in table 5 were obtained from the regression analysis of the experimental data and are not the actual data points. The total force exerted on the eight ties of each bale varied from 2,156 to 20,415 pounds. Analysis of the tie that restrained the highest force on each bale indicated that each tie on a bale should be strong enough

TABLE 2.—*Total force exerted on ties of modified flat bales re-pressed in a compress*[1]

Bale number	Bale weight (pounds)	Moisture content (percent)	Bale circumference[2] (inches)	Platen separation[3] (inches)	Total force[4] (pounds)
1	521	3.80	87.38	14.38	6,090
2	524	3.88	87.38	14.38	6,395
3	522	4.02	80.18	14.50	24,610
4	522	3.62	80.18	14.38	23,660
5	505	3.59	83.62	12.25	3,089
6	493	3.94	83.62	12.25	3,714
7	494	3.56	76.12	12.38	15,390
8	507	3.43	76.12	12.38	14,860
9	501	5.47	87.38	14.38	4,960
10	500	5.03	87.38	14.38	6,180
11	490	7.02	80.00	14.38	14,860
12	503	5.42	80.00	14.38	16,400
13	539	5.59	83.62	12.12	4,020
14	540	5.71	83.62	12.38	3,250
15	500	6.11	76.12	12.25	17,130
16	508	6.10	76.12	12.25	17,895

[1]Based on modified flat bales 25 inches wide and 55 inches long, having 8 ties per bale. Forces were measured 20 minutes after release of platen pressure.

[2]Measured at the tie after the bale was released from the compress (average for 8 ties).

[3]Platen separation to which the lint cotton is re-pressed before the bale was released from the compress.

[4]The total force is the sum of the forces exerted on all 8 ties of the bale.

to restrain approximately 17 percent of the total force exerted on the eight bale ties. This result was in close agreement with the 20 percent reported earlier by Anthony and McCaskill.

Table 6 shows the maximum force that one might expect to be exerted on a tie, determined using the 17-percent figure. The maximum force exerted on each bale tie varied from 367 to 3,471 pounds, depending on the level of moisture content, platen separation and bale circumference. Not all experimental bales were classified as universal density, since the bale circumference

TABLE 3.—*Analysis of variance for the force exerted on bale ties of a compress universal density bale*

Source of variation	Degrees of freedom	F
Attributable to regression	3	85.3**
Deviation from regression	12	- - -
Total	15	- - -

**Significant at the 1-percent level of probability.

TABLE 4.—*Regression analysis of the total force exerted on ties of a modified flat bale re-pressed in a compress*

Variable	Partial correlation coefficient	Correlation X versus Y	Standard error of regression coefficient	Computed t-value	Standard deviation	Standardized partial regression coefficient
Moisture	-0.293^{ns}	0.043	0.017	-1.061^{ns}	1.158	-0.065^{ns}
Bale circumference	$-.976$**	$-.732$	.974	-15.425**	.023	$-.989$**
Platen separation	.950**	.254	.623	10.575**	.036	.721**

^{ns}Not significant at the 5-percent level of probability.
**Significant at the 1-percent level of probability.

TABLE 5.—*Total force exerted on ties of modified flat bales compressed to universal density*[1]

Moisture content (percent)	Platen separation[2] (inches)	Total bale-tie force (pounds) by bale circumference[3]					
		76″	78″	80″	82″	84″	86″
3	12.25	16,332	10,939	7,401	5,057	3,486	2,425
3	14.25	- - -	- - -	20,415	13,947	9,616	6,688
6	12.25	14,523	9,727	6,582	4,496	3,100	2,156
6	14.25	- - -	- - -	18,153	12,401	8,551	5,947

[1]Based on modified flat bales 25 inches wide and 55 inches long, weighing 500 pounds (net) and having 8 ties per bale. Forces were measured 20 minutes after release of platen pressure.
[2]Platen separation to which the lint cotton was pressed before the bale was released from the compress.
[3]The maximum force exerted on any tie may be assumed to be 17 percent of the total force.

TABLE 6.—*Maximum force expected on one tie on modified flat bales compressed to universal density*[1]

Moisture content (percent)	Platen separation[2] (inches)	Maximum individual bale-tie force (pounds) by bale circumference[3]					
		76″	78″	80″	82″	84″	86″
3	12.25	2,776	1,860	1,258	860	593	412
3	14.25	- - -	- - -	3,471	2,371	1,635	1,137
6	12.25	2,469	1,654	1,119	764	527	367
6	14.25	- - -	- - -	3,086	2,108	1,454	1,011

[1]Based on modified flat bales 25 inches wide and 55 inches long, weighing 500 pounds (net) and having 8 ties per bale.
[2]Platen separation to which the lint cotton was pressed before the bale was released from the compress.
[3]The maximum force exerted on any bale tie was assumed to be 17 percent of the total force exerted on all 8 bale ties at the end of 20 minutes.

was intentionally varied to include bales below 28 lb/ft^3. The density of the experimental bales varied from 25 to 33 lb/ft^3.

The forces exerted on bale ties appear to increase with time until they reach a maximum. The results of monitoring the total force exerted on eight ties while the bale remained at rest for 16 hours indicated that approximately 88 percent of the total force exerted on the ties had developed at the end of 20 minutes. At the end of 5 hours, approximately 98 percent of the force had developed. These values hold true only for the particular bale tested, but do indicate that the force exerted on bale ties continues to change with time. Figure 4 is a graphical representation of table 6, expanded to include the increased force at the end of 16 hours.

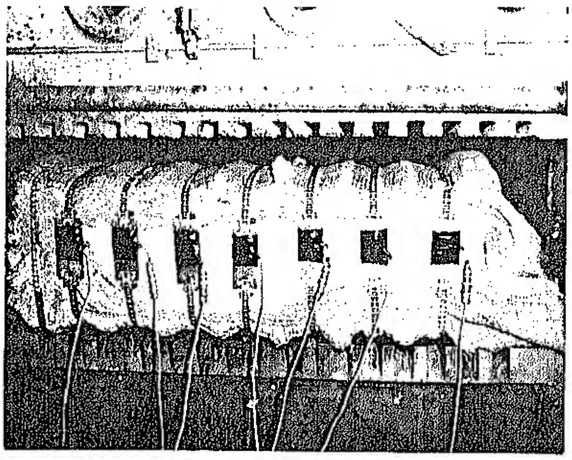

FIGURE 3.—Compress universal density bale with strain-gage transducers mounted on ties.

PHYSICAL PROPERTIES OF COTTON

The grade index and foreign-matter content of each of the experimental bales is shown in table 7. The composite grade index varied from 85 to 100 and the foreign-matter content varied from 2.22 to 3.19 percent. All bales had a staple length of 1¹⁄₁₆ inch. Some lint physical properties such as fibrograph measurements, strength, causticaire, and micronaire are listed in table 8 to identify the properties of the experimental cotton. The values are included for documentation, and no inferences are drawn from them.

TABLE 7.—*Grade index and foreign-matter content of the experimental cotton*[1]

Bale number	Grade index[2]			Foreign-matter content (percent)
	Color	Leaf	Composite	
1	94	94	94	2.78
2	94	94	94	2.71
3	94	85	90	2.22
4	94	94	94	2.27
5	94	94	94	2.58
6	94	94	94	2.83
7	94	94	94	2.64
8	94	94	94	2.60
9	85	85	85	2.70
10	87	91	88	2.59
11	85	88	85	3.19
12	88	91	88	3.07
13	89	94	89	2.98
14	100	100	100	2.43
15	88	91	85	2.71
16	94	94	88	2.60

[1]All values are averages of 3 replications.
[2]All samples were graded "normal" preparation and 1¹⁄₁₆-inch staple length.

ANALYSIS AND CONCLUSIONS

The independent variables—platen separation to which cotton is pressed before the bale is released from the compress and bale circumference at the tie after the bale is released from the compress—have a strong influence over the force exerted on the ties of a bale. Lint moisture content has a substantially smaller influence, but is considered a significant factor. These three variables should be included in selecting bale ties for lint cotton. Since lint cotton is sometimes baled at low moisture content, 3 percent moisture should be the design level. The suggested thickness of universal density bales produced in a compress is 21 inches when measured across the ties. The bale circumference (at the tie) resulting from bales 21 inches thick (at the tie) is not exact but is in the range of 80 to 82 inches. The importance of these variables can be illustrated by two examples.

Example 1.—Platen separation.—If a 500-pound bale of cotton with 3 percent moisture is to have a circumference of 82 inches, the maximum force exerted on each tie will be 2,371 pounds when the bale is pressed to 14.25 inches platen separation before being released from the compress, and 860 pounds when it is pressed to 12.25

inches before being released. This example is based on the force developed at the end of 20 minutes and not on the force that might eventually develop as a result of the resilience of the cotton or of rough handling of the bale. Adjusted for the increase likely to result from cotton's resiliency over a period of 16 hours, maximum forces per tie can rise to approximately 2,694 and 977 pounds, respectively.

Example 2.—Bale circumference.—If a 500-pound bale of cotton with 3 percent moisture is pressed to a platen separation of 12.25 inches before it is released from the compress, the maximum force exerted on each tie will be 1,258 pounds if it is restrained at a bale circumference at the tie of 80 inches, and 860 pounds if it is restrained at a bale circumference at the tie of 82 inches. Analysis of the data indicates that in order to hold a bale to a 21-inch thickness at the tie, each tie must withstand a force of 1,200 to 1,400 pounds, the bale should be compressed to a

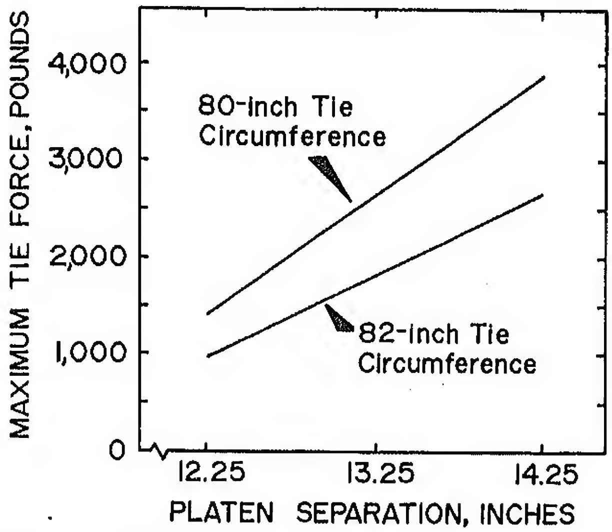

FIGURE 4.—Maximum force expected on one bale tie on a compress universal density bale (with 3 percent moisture) 16 hours after release of platen pressure.

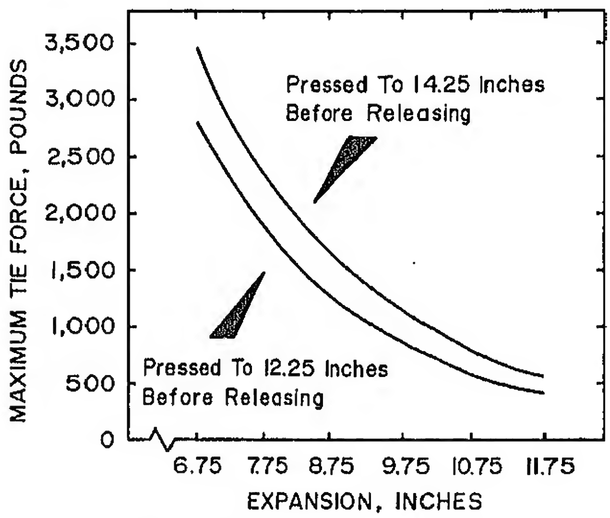

FIGURE 5.—Effect of bale expansion on the maximum force on one tie of a compress universal density bale (with 3 percent moisture) 20 minutes after release of platen pressure.

TABLE 8.—*Some lint physical properties of the experimental cotton*[1]

Bale number	Fibrograph		Strength, ⅛-inch gage (g/tex)	Causticaire		Micronaire
	2.5% span length (inches)	Uniformity ratio		Maturity index	Micrograms per inch	
1	1.04	43	21.5	79	4.6	4.5
2	1.06	41	21.4	77	4.2	4.2
3	1.06	42	22.1	76	4.2	4.0
4	1.06	43	21.6	80	4.7	4.6
5	1.08	43	22.0	78	4.5	4.3
6	1.05	42	21.4	74	4.3	3.9
7	1.08	42	22.4	78	4.4	4.3
8	1.06	42	21.2	76	4.3	4.1
9	1.08	44	21.7	75	3.9	3.8
10	1.07	42	21.1	79	4.1	4.2
11	1.04	46	20.5	81	4.5	4.6
12	1.02	46	20.7	80	4.1	4.6
13	1.08	43	20.8	79	4.6	4.2
14	1.11	46	21.4	81	4.9	4.6
15	1.04	48	20.6	81	4.6	4.9
16	1.05	46	20.7	81	3.9	4.7

[1]Values determined by Cotton Division, Agricultural Marketing Service, Clemson, S.C. Values are averages of 3 replications.

TABLE 9.—*Relationship between maximum force exerted on each bale tie and expansion of the bale after release from compress*[1]

Moisture content (percent)	Platen separation[2] (inches)	Maximum individual bale-tie force (pounds) by bale expansion[3]				
		6.75"	7.75"	8.75"	9.75"	10.75"
3	12.25	2,776	1,860	1,258	860	593
3	14.25	3,471	2,371	1,635	1,137	797
6	12.25	2,469	1,654	1,119	764	527
6	14.25	3,086	2,108	1,454	1,011	709

[1]Based on modified flat bales 25 inches wide and 55 inches long, weighing 500 pounds (net) and having 8 ties per bale.

[2]Platen separation to which the lint cotton was pressed before it was released from the compress.

[3]The maximum force per tie was assumed to be 17 percent of the total force exerted on the 8 bale ties at the end of 20 minutes. The expansion was determined by measuring the bale thickness at the tie before and after the bale was released.

platen separation of approximately 12 inches, and circumference at the tie after release should be 80 inches. In this example the bale would be allowed to expand approximately 9 inches after it was released from the compress. The expansion allowed is the difference between the thickness measurements at the tie before and after the bale is released from the compress. Table 9 shows the relationship between the maximum force exerted on the bale tie and the distance the bale was allowed to expand for the data obtained from this experiment. Figure 5 is a graphical representation of the information in table 9.

Results of this study indicate that bale ties must, as a minimum, be selected on the basis of the three independent variables included in this study plus a safety factor. After tie selection based on the operating levels of moisture content, platen separation, and bale circumference, careful control must be exercised over the actual operating levels to prevent excessive tie breakage.

ACKNOWLEDGMENTS

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